AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CCLXXIV.

(Vol. XIII.—February, 1884.)

WATER POWER WITH HIGH PRESSURES AND WROUGHT-IRON WATER PIPE.

By HAMILTON SMITH, Jr., M. Am. Soc. C. E.

READ FEBRUARY 6TH, 1884.

WITH DISCUSSION.

For the purpose of supplying the placer mines in California with water, many ditches were built on the western slope of the Sierra Nevada, taking their source high up in the mountains, and delivering the water on the tops of the foot-hill ridges, at elevations from 1 000 to 3 000 feet above the great valley of California, formed by the Sacramento and San Joaquin rivers. In many cases the mines for which these aqueducts were constructed have been exhausted or abandoned, and their water is now largely used for power for quartz mining and milling, and for other purposes.

When manufacturing in California assumes large proportions, doubtless most of the motive power will be obtained from these mining ditches, which in the aggregate will afford several hundred thousand horse powers.

The problem presented has been in general the utilization of a small quantity of water—as few of these ditches carry more than 70 or 80 cubic feet per second—with high heads, ranging from 200 to 600 feet.

The Barker reaction wheel (or mill) was first used to a limited extent, but was soon abandoned, owing to its uneconomical use of water. Turbines were then employed, but with unsatisfactory results, as the great speed of the wheel-shafts, due to the velocity of high heads, resulted in excessive wear and tear upon the bearings of the wheel-shafts, and also upon the gates and guides. Partial turbines, or tangential wheels,* were used with better success. In some cases large overshot wheels were built, one at the Sierra Buttes mine having a diameter of 65 feet.

A wheel of very simple form, called the "hurdy-gurdy," was introduced some 20 years or more ago, and has almost entirely superseded other hydraulic motors; it has been improved from time to time, until the latest models now give an astonishingly high percentage of useful effect.

The first part of this paper will be devoted to a description of various styles of the hurdy-gurdy wheel, and an account of some of the methods by which the water is conducted to them, and the power transmitted from them.

The Hurdy-Gurdy Wheel.

The hurdy-gurdy, as first used, was a narrow wooden wheel or disc, built upon a cast-iron spider keyed upon the wheel-shaft, as shown by Sketch 1, Plate X.

The faces of wheels of considerable diameter were from 4 to 6 inches wide; the buckets were square iron castings bolted to the rim, against which the water escaping under pressure from the nozzle impinged. Wheels of this sort were made as large as 21 feet in diameter; when of this size they were sometimes stiffened by light iron tie rods, running from the rim to collars upon the shaft. With high heads the face was banded with wrought-iron, to prevent the jet from splintering the wood.

This simple type possessed the following advantages:

First.—Small cost of construction.

Second.—Comparatively light foundations were required.

---

*These wheels are really modifications of the hurdy-gurdy; the jet generally striking on the inside of the rim, against fixed curved buckets.

Third.—Slow speed of wheel-shaft with high heads, which could be modified at will by change of diameter.

Fourth.—Horizontal wheel-shaft, obviating the necessity of bevel gearing.

Fifth.—The weight of such large wheels, with a high velocity at the rim, was of service in steadying motion of machinery driven, thus affording a cheap form of fly-wheel.

Sixth.—Almost absolute immunity from accidents, the wear and tear being practically *nil.*

These advantages are common to all the forms of the hurdy-gurdy now in use, with the exception of that due to the large wheel.

With this flat bucket the impact force of the jet was only in part utilized, which in no case could be over 50 per cent. of the theoretical power of the water; in practice, an efficiency of not over 40 per cent. could be obtained. The most advantageous periphery speed, measured on the centre line of the buckets, was about 45 per cent. of the velocity of the escaping jet due to gravity $(.45\ (2gh)^{\frac{1}{2}})$.

Mr. Ross E. Browne, of the University of California, with such flat buckets, obtained 40.4 per cent.* as the maximum useful effect on the wheel-shaft, with a periphery speed of about one-half the velocity of the escaping jet (doubtless measured at smallest diameter of the nozzle). A $\frac{3}{4}$-inch nozzle was used, with a head of 50.2 feet, in this experiment.

D'Aubuisson describes somewhat similar *horizontal* wheels as being frequently used in the Alps and Pyrenees, the water being led to them by steeply inclined troughs. Probably the use of a jet, escaping under high pressure from a pipe, is a California invention or modification.

The first improvement upon this simple form consisted in putting flanges on the sides of the rim, with curved sheet iron buckets between, as shown by Sketch 2, Plate X.

A number of experiments were made by the writer with a wheel of this pattern, $17\frac{1}{2}$ feet in diameter; effective heads from 312 to 336 feet; with buckets 4 inches deep, 4 inches wide, set 12 inches apart. Nozzles of various kinds were used; some with a taper, giving a co-efficient of discharge from .944 to about 1.; and others with square-edged thin steel

*Bulletin No. 1, College of Mechanics, University of California, 1883; by Prof. F. G. Hesse and Ross E. Browne. To which valuable contribution on water motors, reference will several times be had in this paper.

rings set in the end of the discharge pipe, whose co-efficients of discharge ranged from .60 to .64.* The jet through the rings gave a somewhat better effect than from the tapered nozzles, although the jet was slightly farther away from the wheel with the ring nozzles, than it was with the tapered ones.

With small nozzles the maximum useful effect was about 35 per cent., with a bucket speed of $.35\ (2\,g\,h)^{\frac{1}{2}}$; with larger nozzles the maximum efficiency was about 46 per cent., with a bucket speed of $.45\ (2\,g\,h)^{\frac{1}{2}}$ The highest power developed in these experiments was 17 horse power, which, for such a heavy wheel as that used, was too little work to show the greatest efficiency.

These tests proved that the best bucket speed depends not upon the velocity of the jet, measured at the smallest area of the nozzle, but

*Experiments showing Discharge of Water through various Circular Nozzles and Rings. 1874.

No.	No. of Nozzle or Ring on Sketch.	Diameter.	Effective Head.	Q.	Velocities of Jet.			Remarks.
					Actual.	Theoretic.	Co-ef. of Discharge.	
1.	1	.0531	322.3	.323	145.8	144.0	1.012	
2.	3	.0850	314.4	.774	136 4	142.2	.959	
3.	"	"	312 1	.759	133.7	141.7	.944	
4.	5 uncut.	.0868	316.1	.813	137 4	142.6	.963	No. 5, uncut.
5.	5 cut-off.	"	332 6	.831	140.4	146.2	.960	No. 5, cut at smallest section.
6.	"	"	335.9	.833	140.8	147.0	.958	
7.	7	.1017	317.9	1.111	136.8	143 0	.957	
8.	"	"	315 6	1.110	136 7	142.5	.959	
9.	2 ring.	.0597	316.3	.240	85.7	142 6	.601	
10.	4 "	.0847	312.6	.511	90 7	141 8	.640	
11.	" "	"	312.2	.509	90.3	141.7	.637	
12.	6 "	.1823	130.1	1.528	58.5	91.4	.640	Total head in this experiment.

The nozzles and rings are shown by sketches on Plate XI.

The nozzles, and discharge pipe into which they screwed, were of cast-iron, first turned and then smoothly polished.

The rings were of saw-plate steel, with square edges; the discharge pipe, at the end of which the rings were set—Nos. 2 and 4—was a smooth casting.

The effective heads for Nos. 1 to 11, inclusive, are given within 2 feet of the truth. Q, for Nos. 1 to 11, was determined by the flow over a sharp-crested iron weir, .866 feet long, by formula of J. B. Francis, modified; the chances are that Q is underestimated 2 or 3 per cent.

Diameters were measured at smallest section of nozzles.

These experiments indicate that with great heads divergent mouth-pieces or adjutages have but slight effect. No. 5 had a divergent end of a length 1.8 times diameter, and gave co-ef. of .963; when cut at smallest section, co-ef. remained .960 and .958. No. 7, with divergent end of a length 2.4 times diameter, had a co-ef. of .957 and .959.

The annular square-edged mouth-pieces were narrow, especially Nos. 4 and 6, and yet show a nearly full contraction of the escaping jet.

practically upon the velocity due to gravity. The ratio of best speed to $(2\,g\,h)^{\frac{1}{2}}$, for the same amount of work done, was about the same with the rings as with the tapered nozzles, although the velocity at the smallest section of the nozzles was one-half greater than through the rings.*

A similar wheel—diameter 12.58 feet, total head 130.1 feet, ring nozzle .1823 foot in diameter, driving a 10-stamp crushing mill, average weight of stamp 693½ pounds, average drop .768 feet, number of drops per minute 62.2—developed 10 *H. P.* of actual work, showing an efficiency of 44½ per cent. Allowing for loss of head in pipe and friction of machinery, this would indicate a duty on the wheel-shaft of fully 50 per cent.

Fig. 3, Plate XII, shows the next important improvement, being the Knight wheel, made of cast-iron, with curved buckets set close together.

The nozzle is a narrow slit, curved to fit the outer edge of the wheel, the idea being to have the jet strike the buckets at as close a distance as is possible. With muddy water the wear on this form of nozzle becomes objectionable; with considerable heads, a jet of circular section will probably show better results.

This wheel has met with great favor, a large number of them being now in use.

At the Providence gold quartz mill, near Nevada City, a Knight wheel did actual work amounting to about 54 per cent. of the power of the water, in addition to overcoming friction of machinery.

Mr. Browne found, in experimenting with curved buckets (section arc of circle), a maximum efficiency on the wheel-shaft of $65\frac{6}{10}$ per cent., with a periphery speed of about 44 per cent. of theoretical velocity of water. This was with a ⅜-inch tapered nozzle, and a head of 50.4 feet.

Fig. 4, Plate XII, shows the Collins wheel, which, when placed at the Providence mill (before spoken of), as a substitute for the Knight, did the same work with $\frac{9}{11}\frac{4}{2}$ths the amount of water.

This mill has 40 stamps, each weighing 750 pounds, drop 8 inches, 92 drops per minute, aggregating work of lifting the stamps 1 840 000 minute foot pounds. There are also one rock breaker and sixteen Frue

* This is doubtless due to the increased velocity of the vena-contracta at its smallest diameter, after the jet has escaped from the ring.

vanners (concentrators), requiring fully 8 *H. P.* (264 000 foot pounds) more, making in all say 2 104 000 minute foot pounds (64 *H. P.*).

This work is done by a Collins wheel, 6 feet in diameter, running 250 turns a minute ; the water is conducted to it through 1 856 feet of wrought-iron pipe (1 156 feet being 22 inches, and 700 feet 15 inches in diameter), and discharged under a head of 389 feet through a 1¾-inch nozzle. The water used amounts to very nearly 136 cubic feet per minute.

Assuming 2 feet head as lost by friction in pipe, $387 \times 136 \times 62.4 =$ 3 284 237 foot pounds per minute; $2\,104\,000 \div 3\,284\,237 = 64$ per cent.* as useful effect in moving machinery.

The wheel is quite a distance from the main line of shafting, the power being transmitted by belts. Allowing for losses of friction in belting, lines of shafting, cams and stamps, there would result an efficiency on this wheel-shaft of over 70 per cent.

The latest, and probably the most efficient, bucket thus far discovered, is known as the Pelton wheel, a perspective view of which is shown by Fig. 5, Plate XII, and a section through the bucket by Sketch 6, Plate X.

The invention consists in splitting the jet as it strikes the biturcation of the bucket. The line of the jet should be tangential to the wheel. Where much power is needed two discharge pipes can be used, and any desired form of nozzle applied.

Mr. Browne found with one of these wheels, which was not built on the most approved model, the following results :

Wheel, 15¾ inches in diameter.

Nozzle, ⅞ths inch, tapered.

Head, 50.2 feet.

Maximum efficiency on wheel shaft, 82½ per cent.

Best speed of bucket, very nearly one-half the velocity of the jet (substantially $\frac{1}{2}\,(2\,g\,h)^{\frac{1}{2}}$).

With the same nozzle, and a head of only 8 feet, he obtained a useful effect of 73 per cent.

---

* The writer determined amount of water used at this wheel by the flow through a standard aperture. The work done is only given with approximate correctness, but in all probability without serious error.

With a ¼-inch nozzle, best result was 75.6 per cent.; with a $\frac{7}{16}$-inch nozzle, best result was 82.6 per cent.

A number of tests of various hurdy-gurdies was made at Grass Valley some months since, under charge of disinterested parties. These experiments appear to have been properly made, with a Prony brake and weir measurement of water, and showed for the Pelton wheel, while doing 107.4 H. P. of work, under a head of 386 feet, the wonderfully high efficiency of 87.3 per cent.* The other competing wheels showed a much lower rate of duty. An inspection of a small Pelton wheel, running at a

* These experiments were made with a Pelton wheel 6 feet in diameter; nozzle, 1.89 inches in diameter; supply main, 6 900 feet long, 22 inches in diameter, with a head of 386½ feet above nozzle.

The water used was measured over an iron weir, ¼ inch thick, 3.042 feet long, without end contractions, as shown by Sketch 7, Plate X.

The depth as measured by a Boyden hook-gauge, reading to .001 inch, was .4146 feet.

The discharge by Fteley's formula of $Q = 3.31\, l\, h^{\frac{3}{2}} + .007\, l$, would be 2.709 cubic feet per second. With water section of 3.04×1.5, velocity of approach was .6 foot; with $h^a = \frac{V^2}{2g}$ head due to this velocity would be .0056; to be safe, $.0056 \times 2 = .0112 = h^a =$ additional head due to velocity of approach. Fteley calls in general $h^a = 1.5\frac{V^2}{2g}$. This makes a total head of $.4146 + .0112 = .4258$; then with same formula as before, $Q = 2.819$ cubic feet per second.

The head lost by friction in pipe, with formula $V = 50\left(\frac{d\ h^f}{l}\right)^{\frac{1}{2}}$ would be $1.8 = h^f$, reducing total head of 386.5 to effective head of 384 7 feet. (The Bourdon gauge used, showed a pressure of from 165 to 162 pounds, indicating a head of say 380 feet.)

The work done was measured by a Prony brake, as shown by Sketch 8, Plate X, bearing vertically down upon a platform scale, and which showed a weight of 200 pounds upon the scale-beam when the brake gear was suspended by a cord from the point *a*, immediately above the wheel-shaft; this made a constant minus correction of 200 pounds. The friction pulley had a face of 12 inches, was kept wet by a jet of clear cold water, did not heat much, and ran without much jumping.

There were thirteen tests made, showing pretty even results. The first four were as follows:

	a. Weight shown by Scale.	b. Net Weight (— 200 lbs.)	c. Revolutions of Wheel-shaft per Minute.	bc.
1	665	465	254½	118 342
2	665	465	255	118 575
3	660	460	256	117 760
4	660	460	256½	117 990
		Totals	1 022	472 667
		Means.....	255½	118 167

very high velocity, showed that it "carried over" a surprisingly small amount of water. This fact proves the excellence of this particular form of bucket.

The writer at first found it difficult to believe in such high percentages, but from the evidence before him is now satisfied that, with a wheel properly designed, and with heads above 100 feet, or even less, a larger amount of work can be gotten out of water by the hurdy-gurdy than by any other form of wheel. Water pressure engines† may possibly give as good or better results, but their great cost (due to the solidity with which their working parts and column must be built, to withstand the shock of arresting the moving water) will prevent them from coming into general use.

Where a wheel is so placed that it will at times be submerged by back water, the turbine is, of course, preferable to any other wheel. In other regards, however, the hurdy-gurdy possesses almost every advantage.

The chief misapprehension as to the hurdy-gurdy has been, in considering it simply as an impact, and not also as a pressure wheel, which, when properly designed, as Mr. Browne points out, it clearly is.

NOTE.—An examination of a hurdy-gurdy with either flat, recessed or curved buckets, while at work, shows that the wheel "carries over" a large amount of water, the force of which is consequently lost, and in fact becomes an additional load to lift.

The arm of the brake (*A B*) was 4.775 feet from centre of wheel-shaft to point resting on the scale, and hence described a circle with a circumference of 30 feet.

The work done was therefore (118 167 × 30) 3 545 000 minute foot pounds = 107.4 *H. P.*

The theoretic power of the water was (2.819 × 60 × 384.7 × 62.4) 4 060 253 foot pounds. Useful effect was, therefore, 87.3 per cent.

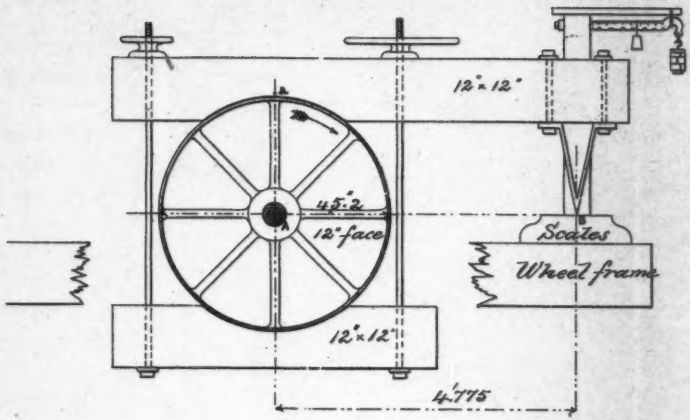
The effective head being 384.7 feet, the velocity of the escaping jet due to gravity would be 157 feet per second, or 9 420 feet per minute. The wheel was 6 feet in diameter, hence circumference = 18.85'; with 255½ turns per minute, ratio of bucket speed to theoretic velocity would be 51 per cent., or .51 $(2\,g\,h)^{\frac{1}{2}}$.

The nozzle of 1.89 inch diameter had an area of .0195 square feet; hence its co-efficient of discharge was .92.

The hook-gauge was only 2 feet back from the weir, and doubtless gave a slightly too small depth of water; the co-efficient of .92 for the nozzle, as above, is rather small, also indicating slightly greater discharge than that estimated. However, these experiments show in any event a duty of fully 85 per cent., which agrees with the results found by Mr. Browne.

† The water-pressure pumping engine, for some time in use at one of the shafts on the Comstock lode in Nevada, is said to show an efficiency of over 90%. There are now three of these engines at work in the State of Nevada, and a paper fully describing them would be of much interest.

Sketch 8.



Sketch 7.

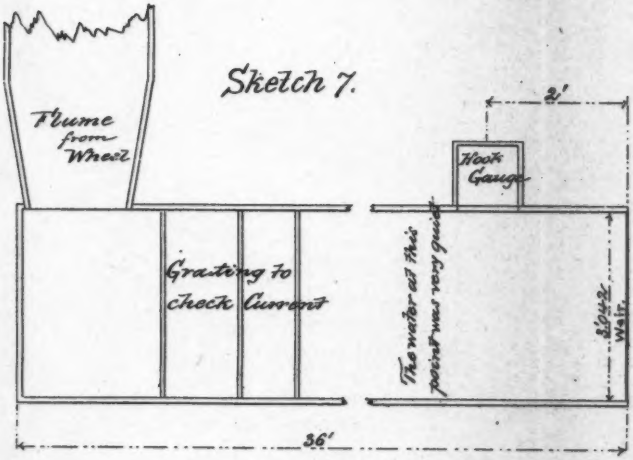
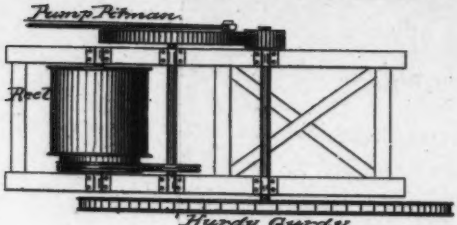
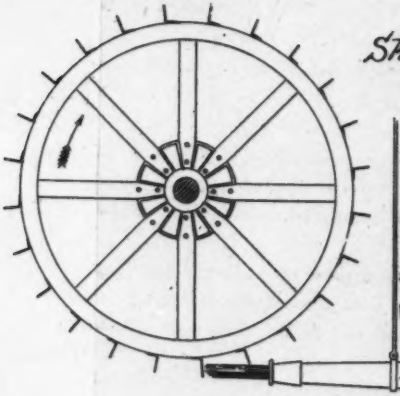


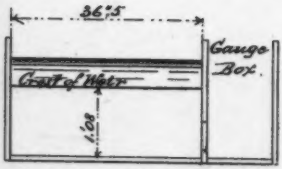
Fig. a.

Fig. b.

Sketch 9.







End View of Flume & Weir

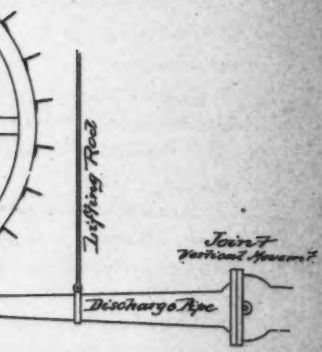
Sketch 2.

Section through Bucket.

Sketch 6.

PLATE X
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIII Nº CCLXXIV.
HAMILTON SMITH JR.
ON WATER POWER
WITH
HIGH PRESSURES.

Sketch 1.



2.

V. ENGRS.
XXIV.
TH JR.
WER
RES.

Mr. Browne says, "When a jet of water strikes a stationary bucket, "as shown in Fig. *a* or *b*, Plate X, so soon as the motion becomes perma- "nent, the wedge-shaped portion of the water, shaded with horizontal "lines, becomes practically stationary."

"When such a bucket is used for a wheel, it is plain that the shaded "portion of the water is 'carried,' and must subsequently escape with "nearly the full velocity of the bucket."

The wedge which is inserted in the Pelton bucket, takes the place of this "dead" water.

Methods of Conducting Water and Transmitting Power.

A description of the mode of using water power for driving the North Bloomfield tunnel in California, some years since, will give a good illustration of some of the advantages of the hurdy-gurdy.

This tunnel was originally about 8 000 feet long, through a slate highly metamorphosed, with its general line passing under a good-sized stream, at a depth of about 190 feet. There were eight working shafts, each about 200 feet deep, which, with the lower entrance or portal, gave sixteen working faces. Diamond drills were used at the lower heading requiring power; the other fifteen headings were driven by hand-work. It was uncertain how much water would be encountered, but from the location it was evident that a large quantity might be struck in any shaft, and hence it became necessary to have ample power at hand at each opening, in readiness for such an emergency.

A pipe main was laid along the general line of the tunnel, with its pen-stock 285 feet vertical above the surface at the upper shaft, and 549 feet above the lowest shaft. It was made of single riveted sheet iron, of No. 14 (Birmingham) gauge, in lengths of 20 feet, put together stove-pipe fashion, with the joints made tight by cloth tarred strips and pine wedges. This pipe had a diameter of 15 inches at the pen-stock, diminishing from this to 13, 11, and 7 inches at its lower end.

From it, short branches, 7 inches in diameter, were extended to the several shafts; it was in one place carried across the stream by a light suspension bridge, some 150 feet long, the trunk of a tree on either side, forming convenient towers. The aggregate length of the main and branches was 9 960 feet, with some 2 500 feet additional, for the branch to the diamond drills. The pipe was laid on the surface of the ground,

its only protection being in places a couple of 1¼-inch planks, tacked together, and placed over it; the range of temperature was from 10° to 107° Fahr. (in the shade). It was inspected by the foreman of the tunnel-work as he daily walked over the line; besides the occasional driving of a few wedges and putting on a band or two, it gave no trouble from leakage, which probably for its entire length did not amount to more than an average of 3 or 4 cubic feet per minute; from time to time a little sawdust was put into the pen-stock.

Three stop-gates were placed on the main, and a separate stop-gate at each shaft, operated by a fine threaded screw, so that the water could be cut off when desired.

Sketch 9, Plate X, shows the arrangement of the machinery for hoisting and pumping, which was identical at the several shafts, except that the hurdy-gurdies varied from 16½ feet in diameter at the upper shaft, to 21 feet at the lowest shaft. The water-wheel moved only in one direction; the pinion on the wheel-shaft drove the spur-wheel, to which the pitman of the pump-bob was attached. On the spur-wheel shaft was a friction gear, driving the hoisting reel; this reel was mounted on sliding blocks, so that hoisting was done by putting it in gear, the empty load being dropped by a friction band.

Changing the size of the water-wheel as the pressure increased, permitted the use of the same pattern of machinery at the different shafts.

The water was brought to the wheel by a discharge pipe, some 9 feet long, having a vertical movement by ball and socket joint, so that at pleasure, by dropping the pipe, the machinery could be run at various speeds, or entirely stopped. At the end of this discharge pipe was a cast tapered nozzle, about 3½ inches in diameter, into which was inserted a ring of saw-plate steel having the desired diameter, and which was held in place by an annular screw-cap. By changing the ring, which only required a few moments' time, any desired amount of water, up to 3 or 4 cubic feet per second, could be discharged against the wheel. The stop-gate was left wide open while the machinery was running.

The pumping was done by eighteen pumps, of Cornish pattern; the largest amount of water pumped from any one shaft was something over 30 cubic feet a minute; the power at hand, however, was ample to have pumped more than twice that quantity. It was rather curious at this shaft to see more water coming from the pumps than was used on the wheel.

The two diamond drills were driven by a small hurdy-gurdy set on

Forms of Nozzles used.

Heads for 1,2,3,4,5 and 7, 312–336 feet.
Head for 6, 130 feet.

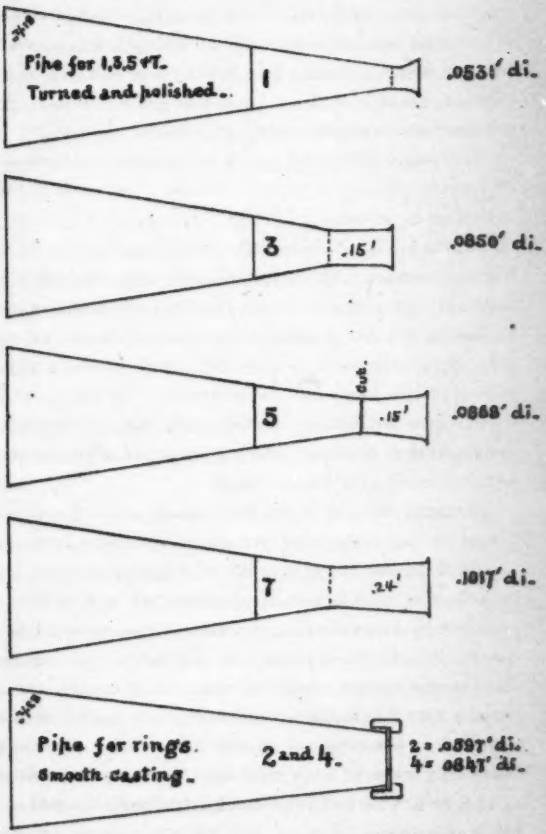


PLATE XI
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIII Nº CCLXXIV.
HAMILTON SMITH Jr.
ON WATER POWER
WITH
HIGH PRESSURES.

the rear of the drill carriage. This, but at another tunnel, was afterwards modified by placing a separate hurdy-gurdy on a sleeve on each drill rod ; the advance movement of the drill being given by hydrostatic pressure on an annular piston, thus doing away with all gearing.

These eight sets of machinery were run for nearly 2½ years' time; the only break being that of a spur-wheel, doubtless caused by the careless dropping of a steel bar between it and its pinion. Aside from this accident, practically, not a dollar was spent for repairs, and the machinery, including the pipe, was in about as good order when the tunnel was finished as when it was first erected.

One man, on a 12-hour shift, operated the machinery at each shaft, besides dumping the cars; two men kept the 18 pumps on the line in order, the principal work being in keeping the suction pipes for the down-grade headings tight; thus a force of 18 men was only required for the 8 shafts.

The cost of the pipe, gates, &c., when put in place, was $14 631, and of the machinery about $60 000.

At the Idaho gold quartz mine, situated near Grass Valley, California, water power has been introduced during the past year (1883), taking the place of steam.

The supply main is of wrought-iron, 22 inches in diameter, 8 764 feet long, buried in the ground below frost line. The joints, as a rule, are riveted together, with occasional lead joints to admit of slight movements in the pipe.* The pipe was coated by placing each joint in a bath of boiling coal tar and asphaltum; to insure the most thorough coating, it is necessary to keep the pipe for 10 or 15 minutes in the boiling mixture. A cast-iron stop-gate is placed at the lower end of the main, and also one at each of the branches. Cast-iron man-holes are attached to the main, which, although they have given no trouble in this particular case, are very objectionable for high pressures, as it is difficult to avoid ruptures with cast and wrought-iron combined, owing to the great difference in the elasticity of the two metals.

The long seams of this pipe are double-riveted, and the round seams single-riveted; at the lower end iron of No. 6 gauge is used.

From the end of the main, the water is led to the several wheels by branches of smaller diameter.

* With buried wrought-iron pipe this precaution is unnecessary, as the elasticity of the iron will admit of the movement due to changes of temperature, without injury to the rivets.

The water is delivered at the hoisting wheel with a total head of 542.6 feet. For power and for mill uses, &c., the required supply is about 8 cubic feet per second; this draught reduces the effective head to say 523 feet.

The work done consists in driving the following described machinery:

A large air compressor—2 cylinders, double acting, air compressed to 75 lbs.—requiring about 140 H. P.

A line of Cornish pumps, forcing the water from a depth of 1 450 feet vertical; 12-inch plungers for upper 800 feet, 6-inch plungers for lower 650 feet, with 6-foot stroke, requiring from 55 to 70 H. P.

Hoisting from a double compartment shaft—two connected winding reels, moving separate cages—requiring 35 H. P., or more.

A few small machine tools and smithy forges, requiring 3 or 4 H. P.

A 35 stamp mill, with concentrating apparatus, &c., requiring about 70 H. P.

The total amount of power required, being say 320 H. P., for which seven Pelton hurdy-gurdy wheels are employed.

The power in all cases is transmitted by systems of manilla rope belting; rope is 2 inches in diameter; grooves in the sheaves or pulleys are slightly oval, so that the rope does not go quite to the bottom; the ropes are horizontal and run very slack (no tightners), with no appreciable slip; the splices are made very long to obtain uniformity in diameter.

This method of transmitting power appears to work most perfectly, and has given excellent satisfaction. It is thought at the Idaho, to be greatly preferable to the gearing formerly in use, when the works were driven by steam (for such work as pumping or hoisting, leather or rubber belting is never used), besides being much cheaper in first cost.

The wheel driving the air compressor is 6 feet in diameter, running 300 turns* per minute, with a $1\frac{5}{16}$-inch nozzle; three ropes are used from wheel-shaft to counter-shaft, and six ropes from the latter to the fly-wheel shaft.

For driving the pumps there are two water-wheels, set on the same shaft, one 5 feet and the other 7 feet in diameter, either of which can be used at will, thus permitting different rates of speed; two nozzles are placed on each wheel, so that if necessary the power can at any time be

* The revolutions per minute of these wheels, as here given, are only approximate; the design was to have the bucket speed $= \frac{1}{2}(2\,g\,h)^{\frac{1}{2}}$.

PLATE XII
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIII Nº CCLXXIV.
HAMILTON SMITH Jr.
ON WATER POWER
WITH
HIGH PRESSURES.

FIG. 3

THE KNIGHT WHEEL

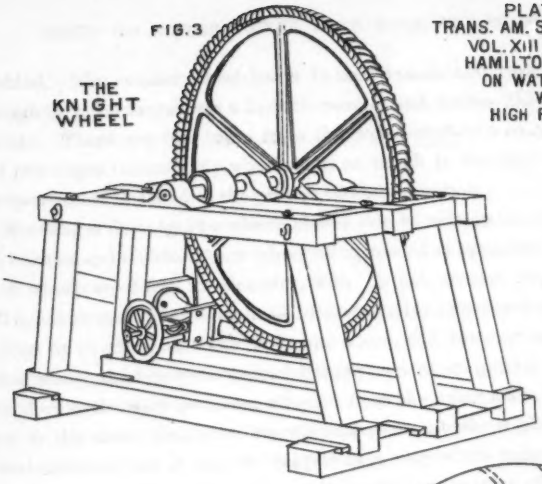


FIG. 4

THE COLLINS WHEEL

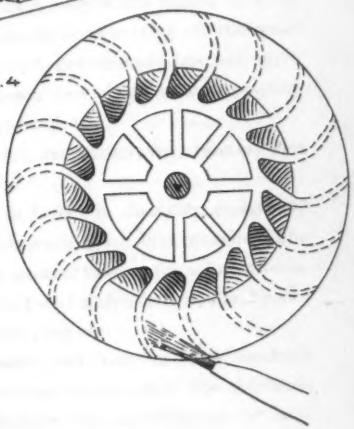
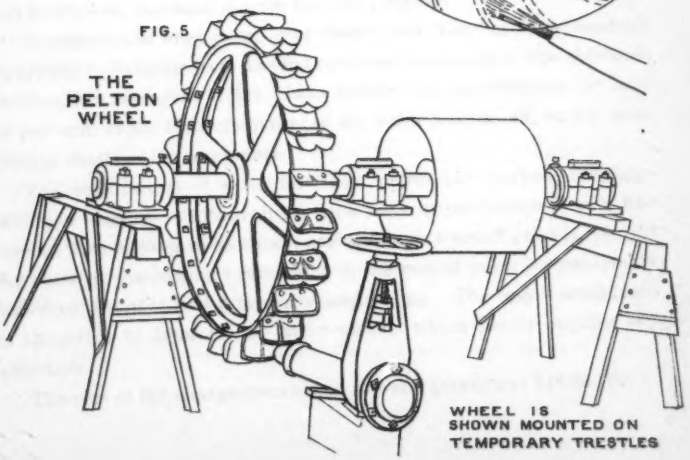


FIG. 5

THE PELTON WHEEL



WHEEL IS SHOWN MOUNTED ON TEMPORARY TRESTLES

doubled. The smaller wheel has a 1¼-inch nozzle, and runs 360 turns per minute; the larger has a 1⅛-inch nozzle, and makes 270 turns per minute. There are two ropes from the wheel-shaft to a counter-shaft, and four ropes thence to fly-wheel shaft, on which is the pinion driving the spur-wheel attached to the pitman of the pump-bob.

Hoisting is done by two wheels placed side by side on the same shaft, the buckets and nozzle of each wheel being placed in opposite directions. Both wheels are 8 feet in diameter, with $\frac{15}{16}$-inch nozzles, and make at full speed about 225 turns a minute. Reversing the movement of the shaft is done by shutting off water from one wheel, and turning water on the other wheel; the two water-gates for these nozzles are quickly opened or closed by hydrostatic pressure, afforded from the water main. In addition to the usual brakes on the winding reels, a brake is placed on the wheel-shaft, so that it can be stopped in a very short period of time. The shock to the pipe by the almost instantaneous cutting off the water at these hoisting wheels (nearly 1 cubic foot per second) has not apparently had any injurious effect. To lessen this shock a compensating balance was designed, but which is not now in use.

A wheel, of small diameter, is used for the smithy, &c., running at a very high velocity.

The wheel driving the stamp mill is 6 feet in diameter, makes 300 revolutions a minute, and is supplied through a $1\frac{3}{16}$-inch nozzle. The head of water at this point is a few feet greater than at the other wheels.

Power is transmitted from the hoisting and mill wheel-shafts by two and four ropes, the same as with the pumping rig.

The amount of work done, or of water used, has not been carefully determined; judging from the indicator cards taken from the old steam engines, the managers of the Idaho believe that an efficiency of fully 80 per cent. of the theoretic power of the water is obtained, on the main driving shafts of the machinery.

The substitution of water for steam power has resulted in a large saving of expense. Although the hills near by are covered with fine forests, thus making wood cheap, and although a round price is charged for water by the company furnishing it, the cost of water is considerably less than that of the wood formerly used as fuel. The cost of attendance is altogether in favor of the water-wheels, which hardly require any attention.

The cost of the change from steam to water power was $46 496.32.

Texas Creek Pipe and Aqueduct.

A description of this work will be of interest, in showing the general practice followed in California for carrying water across deep mountain gorges.

In order to augment its water supply, the North Bloomfield Gravel Mining Company desired to conduct water from a stream known as Texas Creek, in Nevada County, California, across the Big Cañon branch of the South Yuba River into the main Bloomfield flume or aqueduct, which was located on the side of Big Cañon Creek, at a vertical elevation of 620 feet above the bed of the latter stream.

The quantity of water to be carried was about 32 cubic feet per second (1 250 miner's inches), which could be diverted from Texas Creek at a point 480 feet vertical above the Bloomfield flume. An aqueduct about 4 000 feet long, partly of ditch and partly of flume, was needed to bring the water from the catchment dam on the creek to the brow of the gorge. The vertical head for the pipe could therefore be, from a maximum of 460 feet, down to any lesser head; with a head of 460 feet the pipe would be 4 790 feet long, and with a head of 220 feet the length would be 4 290 feet.

Assuming a maximum tensile strain upon the iron of 16 500 pounds per square inch, with the formula for the greatest head of about

$$d = \left(.359 \frac{l}{h} \right)^{\frac{1}{2}}, \text{ [or, } v = 68 \left(\frac{d\,h}{l} \right)^{\frac{1}{2}}, \text{ and } Q = 32\text{],}$$

and a lower value of the co-efficient in the last equation for lesser heads, it was found, by calculation, that the least cost could be obtained with a head from 300 to 350 feet. The head fixed upon was 303.6 feet, with a length of 4 438.7 feet.

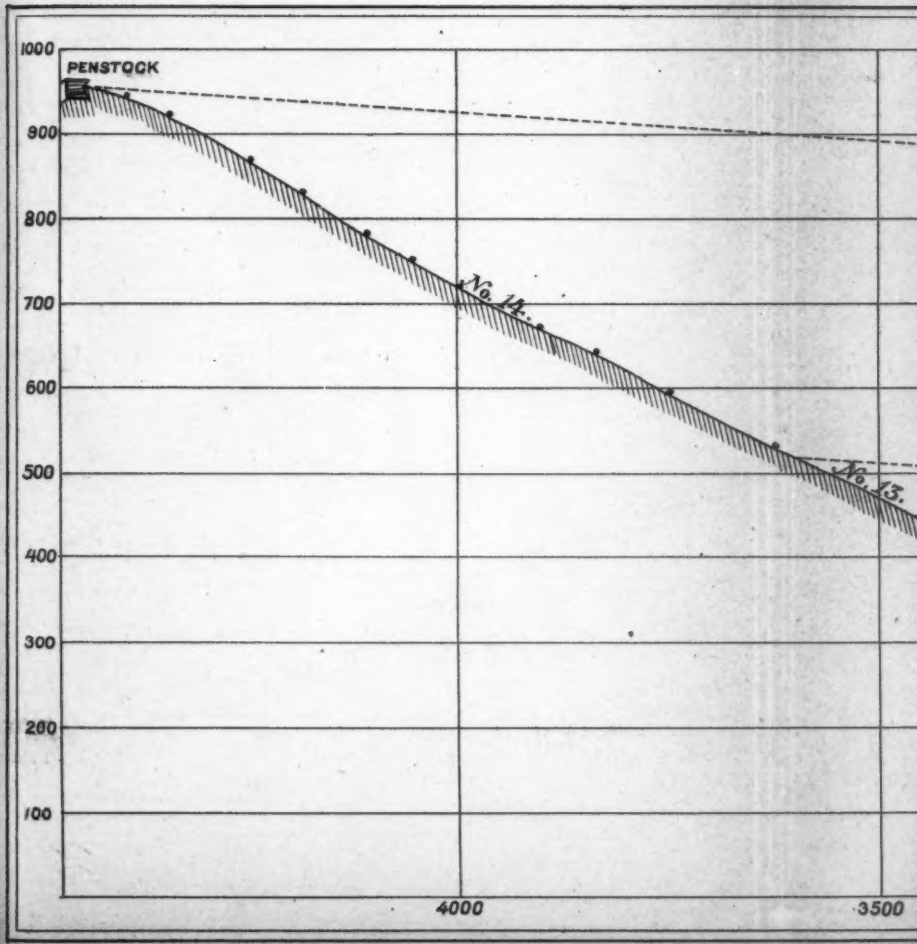
A profile of the pipe, with nearly the same horizontal and vertical scales (the horizontal scale showing slope lengths), is given in Plate XIII; details are given in Plates XIV and XV.

The pipe was of double-riveted sheet-iron, made in lengths of about 20 feet, and of the following thicknesses:

1 349	linear feet,	.083	inch thick.
220	"	.095	"
240	"	.109	"
250	"	.120	"
320	"	.134	"
610	"	.148	"
1 450	"	.165	"

NOTE

Diameter of pipe = ... 17 inches.
Length " " = ... 4439 feet.
Head of water = ... 303 "
Discharge ..... = per second ..... $31\frac{1}{10}$ cu.ft.
Nos 8, 9, &c ..... = thickness of pipe Birm.gauge.
Dots on profile = ... air valves.



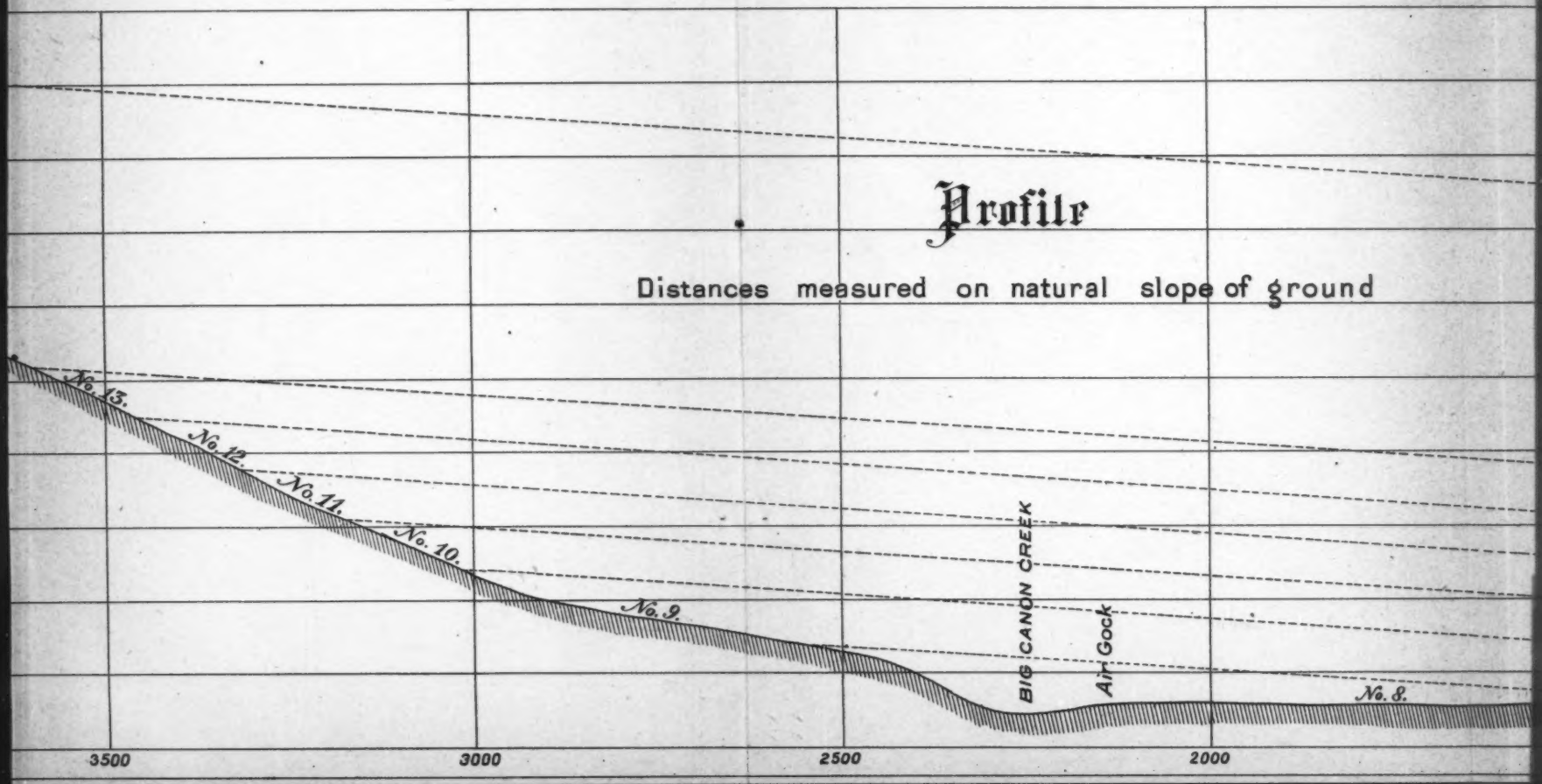
PROFILE OF THE

NORTH BLOOMFIELD GRAVEL MINING COMPANY'S

TEXAS CREEK PIPE

NEVADA CO. CAL.

LAID IN 1878.



PROFILE OF THE

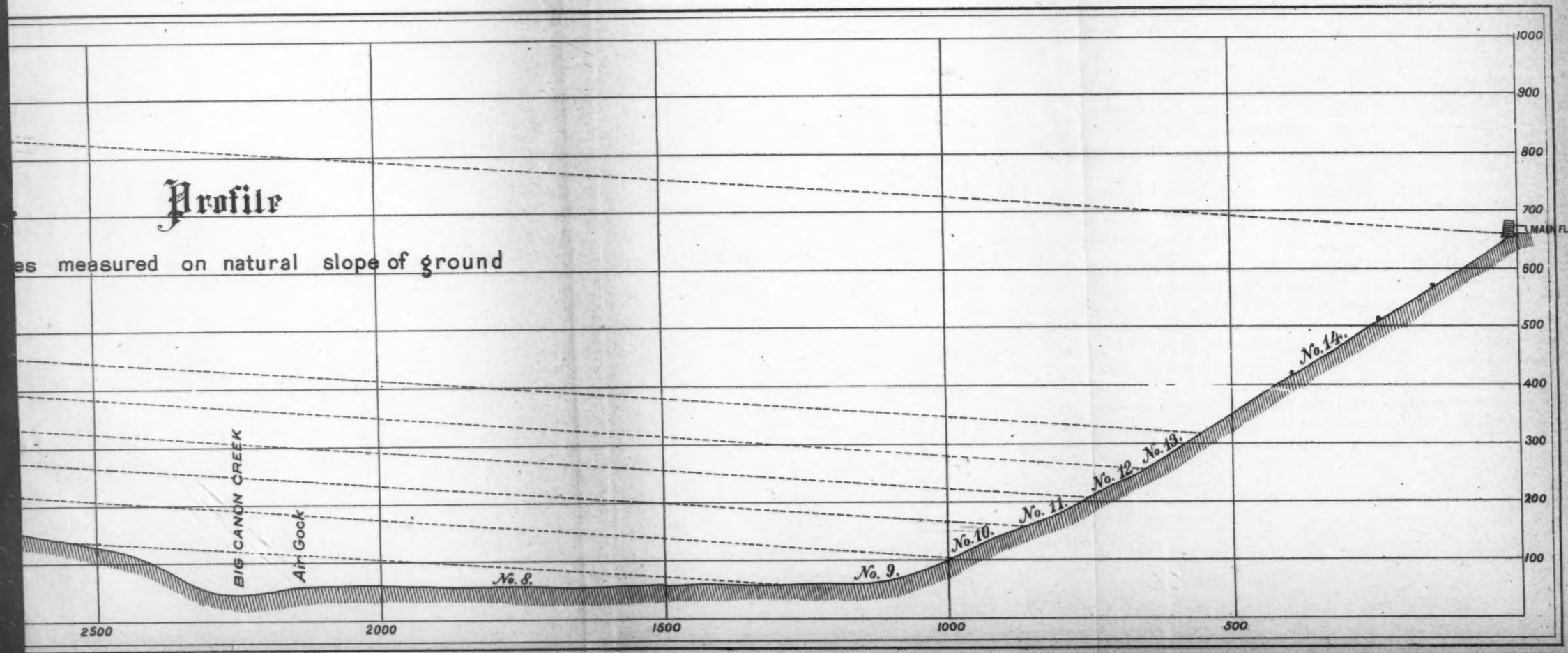
ORTH BLOOMFIELD GRAVEL MINING COMPANY'S

TEXAS CREEK PIPE

NEVADA CO. CAL.

LAID IN 1878.

PLATE XIII
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIII Nº CCLXXIV.
HAMILTON SMITH Jr.
ON WATER POWER
WITH
HIGH PRESSURES.



Some of the iron was of the very poorest quality; the pipe was made by contract in San Francisco, without the supervision of an inspector, as the contractors were a firm of good reputation; the bad quality of the iron was not detected until too late to have it corrected. Since then the writer has always had such pipes—the mines of which he has been the manager using large quantities—made directly on the ground where they are to be used; the pipe-makers, in the latter case, always reject such sheets as are too much below in thickness the standard gauge, and those which show in passing through the rolls a bad quality of iron; tests of each joint by hydrostatic pressure would add too much to the cost.

The maximum tensile strain upon each of the seven thicknesses of iron used, was intended to be 16 500 pounds per square inch. Some of the sheets were below the standard gauge, so that, in reality, the tensile strain is sometimes as high as 18 000 pounds.

The mean diameter of the pipe was 1.416 foot. The entrance into the pen-stock was tapered, so that the co-efficient of contraction was about .92.

For pressures not exceeding say 380 feet, the joints were put together stove-pipe fashion. For greater pressures the joints were made by an inner sleeve riveted on one end of the joint, with an outer lap-welded band, as shown by Plate XIV; lead was run into the space between the outer band and the pipe, and then tightly driven up by caulking irons.

The pipe was laid under the bed of the Big Cañon Creek, a large stream when in freshet, where the head below the hydraulic grade line was 760 feet.

Some of the lead joints leaked slightly at first, but this was soon remedied by more careful caulking.

No man-holes or escape gates were used.

The pipe for the larger part of the year is not filled at its upper end; when such is the case, the water at the inlet carries down the pipe a great quantity of air, for which escapes must be provided to prevent a jarring or throbbing, which would soon destroy the pipe. The escape air valves used, are shown by Plate XV. They consist simply of a heavy flap valve of cast-iron, with recess for lead filling to give greater weight, set on top the pipe, seating on a vulcanized rubber cushion, and swinging on a loose hinge. When the pipe is only partly filled with water the valves drop down by their own weight, allowing the air to freely escape; when the water rises above the level of a valve, it is

tightly closed by the resulting pressure. There are 14 of these valves, those on the lower end being designed to allow air to freely enter the pipe in case it should burst in the deeper portion, and thus prevent any collapse from atmospheric pressure.

The valves have answered the desired purposes most effectually.

The pipe was hauled over a road built to the inlet end, and shot down the mountain side by means of a V-shaped trough of wood. For the lower end, the joints were hauled up the cliff side into place by a crab worked by horse-power.

On steep inclinations the pipe was held firmly in place by wire ropes fastened to iron pins in the solid rock, as shown by the sketch.

The covering of earth and stone was from 1 foot to 2 feet in depth; with steep slopes the earth was kept from sliding by rough dry walls, or by cedar plank placed crosswise.

The pipe was laid in 1878; the first year it broke twice, owing to the wretched quality of the iron; since then it has given no trouble, and has required practically no attention.

The cost of this work—ditch and flume 4 000 feet, and pipe 4 440 feet—was $23 779.53.

A comparison of the relative values of n, in the formula $v = n\ (r\ s)^{\frac{1}{2}}$, for the foregoing ditch, flume and pipe, will be instructive.

The ditch has a width on the bottom of 3 feet, on the top of 6 feet, with a depth of 3 feet, and an inclination of 20 feet per mile; its sides are rough, being in part cut through the rock and with sharp curves, although fairly regular—with a flow of about 1 300 miner's inches (32.8 cubic feet per second), the ditch runs about full.

Therefore:

$$a = \frac{6+3}{2} \times 3 = 13.5\ ;$$

$$r = \frac{a}{3.3+3+3.3} = 1.41\ ;$$

$$s = \frac{20}{5\,280} = \frac{1}{264}\ ;$$

$$Q = 32.8, \text{ hence } v = \frac{Q}{a} = 2.43\ ; \text{ and}$$

$$n \quad \left(\text{in } v = n\,(r\ s)^{\frac{1}{2}}\right) = 33.$$

PLATE XIV
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIII Nº CCLXXIV.
HAMILTON SMITH Jr.
ON WATER POWER
WITH
HIGH PRESSURES.

SCALE = 1:20

EMBEDMENT OF PIPE

LEAD JOINT

The flume is of unplaned boards, rectangular, 2.67 wide × 2.83 deep, with an inclination of 32 feet per mile. There are sharp curves, although these were made as regular as was practicable; the boiling action of the water passing around these curves brought the flow line ($Q = 32.8$) nearly up to the top of the sides; with a straight flume of the same size, the water would have doubtless stood several inches lower.

Therefore,

$$a = 2.67 \times 2.83 = 7.56;$$

$$r = \frac{a}{2.83 + 2.67 + 2.83} = .908;$$

$$s = \frac{32}{5\,280} = \frac{1}{165};$$

$$Q = 32.8, \text{ hence } v = \frac{Q}{a} = 4.34; \text{ and}$$

$$n = 59.$$

With the pipe,* 1.416 diameter,

$$r = \frac{d}{4} = .354\,;\ Q = 31.69\,;\ v = 20.13$$

Allowing for loss of head due to imparting velocity to water, and for contraction,

$$s = \frac{296.1}{4\,438.7}; \text{ and } n = 131.$$

We hence have the following values of n, in $v = n\,(r\,s)^{\frac{1}{2}}$, Q being nearly constant:

Rough ditch, with sharp curves..... 33.
Rectangular flume, with sharp curves..... 59.
Wrought-iron pipe, with easy curves, coated with asphalt, but with rivet-heads forming noteworthy obstructions ($m = 65.5$, and $2\,m = n$).....131.

* *Vide* pp. 120–122, Transactions Am. Soc. of C. E., for year 1883.

DISCUSSION.

THE CHAIR (Vice-President WILLIAM H. PAINE).—The paper just read is now the subject for discussion. Mr. Smith will doubtless be pleased to answer any question suggested by his paper, which presents many points of interest.

HAMILTON SMITH, Jr., M. Am. Soc. C. E.—At the outset I would like to ask a question myself. We use on the Pacific Coast, for carrying water under pressure, almost exclusively wrought-iron riveted pipe; cast-iron is only used in the larger cities, and there for distributing mains, where frequent connections are necessary; the main supply for San Francisco is brought from storage reservoirs, some fifteen or twenty miles distant, by two riveted, sheet-iron pipes, into distributing reservoirs within the city limits. As an illustration of the durability of such pipe, I can instance two pipes laid side by side in 1868 by the North Bloomfield Company, each 26 inches in diameter, of No. 16 iron (.065 inch), single-riveted, with a maximum tensile strain upon the iron of about 11 500 pounds per square inch; these pipes have had water running through them an average of ten months in the year; after 16 years of use they seem to-day to be in nearly as good order as when first laid. The canal feeding them often carries along its bottom considerable quantities of sand and gravel, which passes through the pipes, and one would have supposed that the resulting wear would before this have cut through such thin iron. Now, my question is this: If on the Pacific it is safe and economical to use wrought-iron supply mains, why can they not be used here?

WILLIAM R. HUTTON, M. Am. Soc. C. E.—Have those pipes last spoken of been taken up and examined?

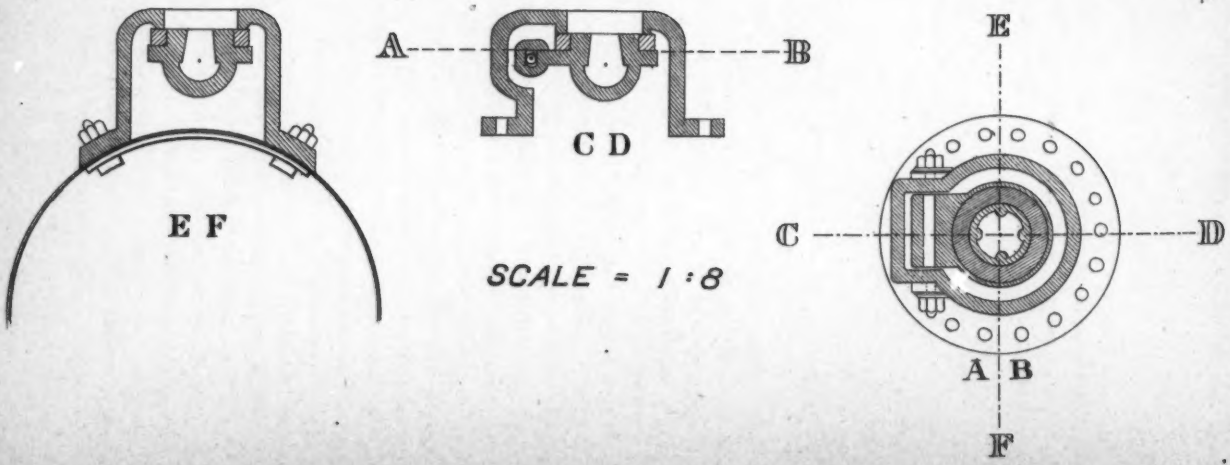
Mr. HAMILTON SMITH, Jr.—They have never been moved since they were first laid.

Mr. ALBERT H. EMERY.—What is the speed of the rope transmission at the Idaho mine, and what are the sizes of the sheaves used there?

Mr. HAMILTON SMITH, Jr.—I cannot give at the present moment either with exactness; the Idaho manager thinks that with a speed of 4 500 feet per minute, a manilla grass rope, 2 inches in diameter, will safely transmit 40 H. P. In San Francisco, where cotton rope made in Dundee, and laid up with tar, is chiefly used, for the same size of rope

PLATE XV
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIII Nº CCLXXIV.
HAMILTON SMITH JR.
ON WATER POWER
WITH
HIGH PRESSURES.

AIR VALVE



a speed of only 1 600 feet per minute is thought to be safe for 40 H. P.

Mr. ALBERT H. EMERY.—What distance were the sheaves apart?

Mr. HAMILTON SMITH, Jr.—From 40 to 80 feet; within reasonable limits, the farther apart the better.

E. B. DORSEY, M. Am. Soc. C. E.—I have seen them over 100 feet apart.

F. O. NORTON, F. Am. Soc. C. E.—Are the ropes greased?

Mr. HAMILTON SMITH, Jr.—At the Idaho they are not.

Mr. ALBERT H. EMERY.—The lining of the grooves in the sheaves is iron?

Mr. HAMILTON SMITH, Jr.—Yes. The manager of the Idaho writes me, after a year's experience with this rope transmission, that it has given perfect satisfaction.

F. COLLINGWOOD, M. Am. Soc. C. E.—Is it as good as wire rope?

Mr. HAMILTON SMITH, Jr.—Those who have used manilla and cotton rope prefer them to wire; from what I have seen of this system, I would now feel safe in using it for the transmission of power upon a very large scale.

THEODORE COOPER, M. Am. Soc. C. E.—What pressure was there upon the Bloomfield tunnel water main?

Mr. HAMILTON SMITH, Jr.—A maximum pressure at the lower end of 550 feet, or say 240 pounds per square inch.

Mr. THEODORE COOPER.—How were the joints of the pipe put together?

Mr. HAMILTON SMITH, Jr.—Each joint is generally about 20 feet long, with one end larger than the other; a strip of tarred canvas is placed around the smaller end, and this is forced into the larger end of the next joint of pipe, with large sizes, by a jack screw, and with small sizes, as 7 inches, by driving with a heavy sledge; if the joints leak, then small pine wedges are driven in; in the hydraulic mines it is necessary to frequently move the pipe; hence it is essential that it shall be as light as possible, with these stove-pipe joints, and laid upon the surface of the ground, so that it can be very easily and quickly taken apart; where the ends fit nicely, very often neither canvas nor wedges are necessary, that is, for heads of less than 300 feet.

Mr. THEODORE COOPER.—What prevents the pipe from pulling apart?

Mr. HAMILTON SMITH, Jr.—There is no danger of this where the pipe has no sharp bends; at bends the pipes must be strongly braced on the outside of the bends.

A. FTELEY, M. Am. Soc. C. E.—What prevents the water from forcing off the canvas strips?

Mr. HAMILTON SMITH, Jr.—As before explained, the canvas is wrapped around the smaller end, and the joints are forced together by pressure, either by sledging or jack-screws.

Mr. E. B. DORSEY.—Very frequently the hydraulic miners do not use canvas for the joints.

Mr. HAMILTON SMITH, Jr.—In our hydraulic mines, with 22-inch pipe laid on the surface of the ground, with joints made in this rough manner, and with pressures of 400 feet, the leakage is very slight.

Mr. ALBERT H. EMERY.—Are the pipes laid straight?

Mr. HAMILTON SMITH, Jr.—No, they have many bends, often quite sharp; at these bends the pipe must be well braced, especially on the upper quarter of the outer side of the bend.

Mr. THEODORE COOPER.—Does the iron of this thin pipe rust, and thus lose its strength?

Mr. HAMILTON SMITH, Jr.—When properly tarred or coated, there is but little danger of rust; the instance I have already given of very thin pipes 16 years in use, with a large tensile strain, is sufficient proof of this. Where water highly charged with sulphate of iron (copperas) trickles over a pipe, then I have seen it rapidly attacked by rust.

Mr. A. FTELEY.—The outside of the pipes are coated?

Mr. HAMILTON SMITH, Jr.—Both outside and inside. The proper way to coat pipes is to have an iron tank large enough to hold a single joint, 22 feet being about the longest size. In this tank the coating mixture is placed, consisting of asphalt, coal tar, a little oil, and sometimes a little rosin, if it is desired to have a hard surface. This mixture is brought up to boiling temperature, and the pipe is allowed to remain in it for, say, ten minutes, until it has become thoroughly heated, and acquired the same temperature as the mixture.

Mr. ALBERT H. EMERY.—How are the pipes dried?

Mr. HAMILTON SMITH, Jr.—After immersion in this bath each joint is hoisted out of the tank, and laid upon trestles in the air and sun.

Mr. ALBERT H. EMERY.—Are you ever troubled with air in your inverted siphon pipes?

Mr. HAMILTON SMITH, Jr.—When such a pipe is first filled, then escapes for the air must be provided at the anticlinal points along its length; after the pipe is once filled with water, and a constant stream flowing through it, then no air escapes or valves are necessary.

Mr. A. FTELEY.—Then you do not use air valves along these pipes?

Mr. HAMILTON SMITH, Jr.—It is necessary to provide valves for the escape of air, when the supply of water is not sufficient to fill the pipe at its upper end. At the Cherokee pipe, in California, with which Mr. Dorsey is quite familiar, when it was first laid, in 1871, there was an insufficient supply of water, and much trouble was experienced by the water at its upper end carrying into the pipe large quantities of air, which, before it made its way out of the pipe, resulted in tremendous shocks or jars. After the supply of water was sufficient to fill the pipe, then no further trouble from this cause has been experienced.

In the Texas Creek pipe, built by me (4 440 feet long, with the great head of 300 feet), and which is filled only a short period in the year, I attached at the upper end a number of automatic flap escape air valves, and there we have had no trouble whatever. In the hydraulic mining pipes, inside iron flap valves lined with leather are placed every few hundred feet apart, so that in case the pipe should burst at its lower end, and hence be very rapidly emptied, then the air rushes in through the valve holes, and prevents the pipe from collapsing by atmospheric pressure.

Mr. A. FTELEY.—What pressure does that Cherokee pipe sustain, and how long is it?

Mr. HAMILTON SMITH, Jr.—That pipe is about 13 000 feet long, 30 inches in diameter, with a maximum pressure of 887 feet below the hydraulic grade line; at that point the iron is $\frac{7}{8}$ths inch thick, double-riveted; the lightest iron used in the pipe is $\frac{1}{1\,2}$th inch thick; the highest tensile strain is 17 549 pounds per square inch.

Mr. E.B. DORSEY.—A short time since I wrote to the Superintendent of the Spring Valley Mine, at Cherokee, Cal., asking him in regard to the condition of this pipe; he reported that notwithstanding its constant service of 14 years, it is now in good condition, showing no signs of decay. This is remarkable, as at the upper ends of the pipe, where the pressure does not exceed 180 feet, the iron is only $\frac{1}{1\,2}$th of an inch thick.

San Francisco has for many years been almost altogether supplied

with water brought through wrought-iron mains. Recently I wrote to the President of the Spring Valley Water Co., which supplies that city with water, asking about the durability of these pipes. He informs me that there was no sign of weakness in them, although some of the pipes had been in use over 20 years. The experience there has shown a coating of asphaltum, when well applied, to be a perfect protection against rust. This company is now increasing its water supply, by bringing in the drainage from the Calaveras water shed, crossing the San José valley by a wrought-iron pipe 5 feet in diameter, 24 miles long, under a pressure of 500 feet vertical.

Virginia City, Nevada, is supplied by water brought from the Sierra Nevada, crossing Washoe Lake and Valley, over 2 miles across, with a maximum vertical pressure of 1 720 feet, equal to 740 pounds per square inch, there being two pipes laid side by side.

The conservative English engineer has also commenced to use for water-works long lines of pipe under high pressure, instead of the aqueduct that has heretofore been so popular. Works were commenced in 1881 to supply Liverpool, England, with 52 000 000 gallons of water daily from the Vyrnwy River, in North Wales. The impounding reservoir has an elevation of 820 feet. Cast-iron pipes will be laid from there to the service reservoir, near Liverpool, at 277 feet above mean tide; the pipe line, 64 miles long, crossing the Weaver River in 11 feet of water, and the Mersey River, 660 feet wide, in 21 feet of water; in both cases in dredged channels on the bottom of the river. Vertical pressure of water, about 400 feet.

Thomas Hawksley, the distinguished engineer, is a very strong advocate of this plan; through his recommendation and advice it was adopted, being in his judgment durable and safe.

Mr. Hamilton Smith, Jr.—The Spring Valley Water Co., of which Mr. Dorsey has spoken, found it cheaper to lay wrought-iron pipes than to build an aqueduct for the supply of San Francisco.

Charles E. Emery, M. Am. Soc. C. E.—When a boy, I made a boiler of stove-pipe, with wooden heads, on which I carried 30 pounds pressure of steam.

Mr. F. Collingwood.—I would like to hear something more about these California pipes.

The Chair.—In early days in California twilled cloth was used to carry water. I have seen thin cloth sewed into hose, through which

water was carried under a head of 12 feet, to wash the placers. If the water was clear it passed through the cloth, but when muddy the interstices of the cloth became filled, and it was practically tight.

Mr. ALBERT H. EMERY.—What diameter was this hose?

THE CHAIR.—Six inches. A good many strange things can be seen in California, which people here would hardly think possible.

I remember one rather amusing incident there. In order to carry water across a winding ravine, a party of Yankee miners laid such a hose of some length, with a slight inclination, and at its lower end rising 20 feet vertical, and discharging into another ravine; the discharge end was, of course, lower than the inlet, but from the configuration of the ground an uneducated eye would have judged that the first part of the hose was about level, and hence it seemed very surprising to see the water all at once rise the 20 feet. A party of Germans noticed with wonder this effect, and laid for their claim a hose nearly level from its inlet, giving it at the lower end a similar vertical ascent of 20 feet. To their chagrin nc water would run through, and they could not get it through their heads how the Yankees could make water run up hill where Germans could not.

Mr. HAMILTON SMITH, Jr.—When I first went to California, in 1869, canvas hose of double heavy duck was still in use for pressures of nearly 200 feet; this was before the invention of the "monitor," which is an iron discharge pipe, working on an universal joint; since this invention no hose has been used in the mines.

Mr. CHARLES E. EMERY.—In these hurdy-gurdy wheels what is the action of the jet as it escapes from the bucket? Does the water turn back, or does it continue straight forward?

Mr. HAMILTON SMITH, Jr.—With a perfect wheel, the water, after striking the bucket, should lose all velocity, and fall by gravity into the sluice, under the wheel, which carries off the discharge water.

Mr. CHARLES E. EMERY.—Does it drop directly down?

Mr. HAMILTON SMITH, Jr.—It should do so with a perfect wheel, as stated in the paper read. The more imperfect types of the hurdy-gurdy "carry over" a large amount of water; one of the marked features of the Pelton bucket is the small amount of water "carried over," even with a small wheel running at very great velocity.

THE CHAIR.—I remember one of the largest water-power wheels put up in the California mines; it was a narrow overshot, said to be 90 feet

in diameter; soon afterwards the wheel just described was first introduced.

Mr. F. COLLINGWOOD.—Who is the inventor of this Pelton wheel, and how did he arrive at this peculiar form of bucket?

Mr. HAMILTON SMITH, Jr.—He is a village carpenter, who lived where there were convenient opportunities for testing such wheels. He bought and studied Mr. Francis' "Lowell Experiments," constructed a Prony brake and a weir to measure the water used, and with these made continuous tests, until he arrived at the peculiar form of bucket and setting which he determined gave the highest efficiency.

Mr. A. FTELEY.—There have lately been built in New England, turbines showing a very large rate of useful effect—as high as 83 or 84 per cent. I have seen this turbine, and was much impressed with its high efficiency. In the case referred to the rate of efficiency given is entirely reliable, being determined, for each wheel manufactured, by systematic tests made with a measuring apparatus of the most approved kind, under able engineering supervision.

Mr. CHARLES E. EMERY.—I would like to ask if any one present is familiar with the operations of turbines under high heads.

Mr. HAMILTON SMITH, Jr.—Turbines with high heads have been used for motive power in driving the great Alpine tunnels—the Mont Cenis, Saint Gothard and Arlberg. It is stated that much trouble has been there experienced in the wear upon the wheel-shafts, guides and gates. In California this wear was so objectionable, that with perhaps nearly 800 wheels now in operation, there is not, to my knowledge, a single turbine at work.

Mr. E. B. DORSEY.—I do not know of a single one.

Mr. HAMILTON SMITH, Jr.—In testing a turbine the wheel is, of course, in as perfect order as can be; after a few months of wear—certainly with high heads—its efficiency would be found to have much diminished. With a hurdy-gurdy the efficiency will remain the same after years of wear.

Mr. A. FTELEY.—Will not the iron buckets wear out with a jet of great velocity?

Mr. HAMILTON SMITH, Jr.—Hard cast iron will last a long time, and the cost of replacing such buckets is insignificant.

Mr. F. COLLINGWOOD.—I should think that such wheels would be good for small powers driven by city water-works.

Mr. HAMILTON SMITH, Jr.—Yes, they seem especially suited for such purposes.

Mr. F. Collingwood.—What efficiency did I understand you to say could be obtained from this Pelton wheel with small heads?

Mr. Hamilton Smith, Jr.—Mr. Browne, with a head of 50 feet, got 82½ per cent., and with a head of 8 feet, 73 per cent.

Mr. A. Fteley.—I would like to have some more information in regard to those Virginia City pipes.

Mr. Hamilton Smith, Jr.—The first laid was of double-riveted wrought-iron about 11 inches in diameter, with the joints connected by lead filling of an outer band and inner sleeve. A good deal of trouble was first experienced in getting these joints tight, as the great pressure forced out the lead in several of the connections. The second was a lap-welded tube 10 inches in diameter, generally united by outside screw couplings, with occasional lead joints to admit of expansion. This latter pipe gave no trouble at all, and it was found that expansion joints were not necessary.

George S. Greene, Jr., M. Am. Soc. C. E.—Were these pipes buried in the ground?

Mr. Hamilton Smith, Jr.—Yes; the lap-welded pipe was put together in the trench during the daytime, and early in the following morning, before the sun had risen, the section of pipe connected together was covered with earth while it had a comparatively low temperature.

Mr. George S. Greene, Jr.—What is the temperature of the water running through these pipes, and also of the air at this point?

Mr. Hamilton Smith, Jr.—The water varies between say 73° and 36° Fahr., and the air in Washoe Valley from 100° in the shade to perhaps 20° below Fahr.

Mr. Theodore Cooper.—Does iron corrode when coated in the manner you have described?

Mr. Hamilton Smith, Jr.—When properly done it seems to be a perfect protection; when the pipe is simply painted the protection is imperfect. The secret of a thorough coating, consists in raising the temperature of the pipe to that of the boiling mixture in which it is immersed.

Mr. Theodore Cooper.—What is that temperature?

Mr. Hamilton Smith, Jr.—I have never determined it.

A Member.—I believe between 350° and 400° Fahr.

Mr. Theodore Cooper.—I have been told in the pure air of Colorado uncoated iron pipe will not rust; is that a fact?

Mr. HAMILTON SMITH, Jr.—I should doubt the truth of such a statement. In California iron will rust about as soon as anywhere else.

Mr. THEODORE COOPER.—What were the co-efficients of discharge with the high heads spoken of?

Mr. HAMILTON SMITH, Jr.—Through rings from .60 to .64, and through nozzles from .94 to 1. My experiments agree with those of General Ellis, in showing through square-edged orifices the co-efficient of discharge is the same for high, as for heads of 2 or 3 feet.

Mr. CHARLES E. EMERY.—In order to obtain a greater discharge upon your Bloomfield wheels, you simply used a larger ring?

Mr. HAMILTON SMITH, Jr.—Yes; this was very quickly done; the water was shut off only for a few moments to make the change.

Mr. CHARLES E. EMERY.—Turbines need not necessarily be mounted upon vertical shafts; they are sometimes placed upon horizontal shafts; the principle of the wheel is the same in either case.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CCLXXV.

(Vol. XIII.—February, 1884.)

STRUCTURAL STEEL.

By EDWARD B. DORSEY, M. Am. Soc. C. E.

READ FEBRUARY 20TH, 1884.

WITH DISCUSSION.

Within the last fifteen months I have investigated the relative merits of the different kinds of steel and wrought-iron for structural purposes. Such investigation has necessitated two trips to Europe and much correspondence, and has taken more of my time than most engineers can devote to any special subject. I propose to give in this paper the result of such investigations, in hopes of being of service to those who cannot spare the time to investigate for themselves.

My investigations were principally confined to Europe, for the reason that the experiences there in steel have been much longer and more extended than in this country.

The usual steel for structural purposes is called generally in England and here "mild steel," and by Krupp and most of the Germans "homogeneous iron." This last, I think, is the most appropriate name.

Its characteristics are greater ductility and malleability, and less tensile strength, than hard or tool steel.

There is no dividing line between hard and mild steel. In general terms, the tensile strength, hardness and brittleness increase with the carbon, and as the carbon decreases so does the tensile strength and hardness, and the ductility, malleability and toughness increase. As silicon, phosphorus and other impurities have somewhat the same effect as carbon, the consumers in Great Britain generally rely more upon the good reputation of the manufacturer, and the physical tests made, than upon the chemical composition; the consumer stating the physical tests the steel must stand—the manufacturer, in his discretion, uses the chemical composition that will produce the required metal.

The British Admiralty, the British Board of Trade, and Lloyd's Register of England have adopted rules for testing structural steel. I think it advisable to give the following full synopsis of them, as they show the conclusions arrived at after long experience and experimenting.

(The ton named in this article is the long ton of 2 240 lbs.)

British Admiralty.—*Tensile test.*—"Strips cut lengthwise to have an ultimate tensile strength of not less than 26, and not exceeding 30 tons per square inch of section, with an elongation of 20 per cent. in a length of 8 inches."

Bending test.—"Strips cut crosswise or lengthwise 1½ inches wide, heated uniformly to a low cherry red and cooled in water of 82° Fahrenheit; must stand bending in a press to a curve of which the inner radius is one and a half times the thickness of the steel tested."

"The ductility of every plate, etc., is to be ascertained by the application of one or both of these tests to the shearings, or by bending them cold by the hammer."

"One plate, etc., to be taken for testing from every invoice, provided

the number of plates, etc., does not exceed fifty. If above that number, one for every additional fifty or portion of fifty. Steel may be received or rejected without a trial of every thickness on the invoice."

LLOYD'S REGISTER.—Both ship and boiler steel is tested by Lloyd's surveyors.

Tensile test.—Boiler plates, 26 to 30 tons per square inch, and 20 per cent. elongation in 8 inches.

Ship plates, 27 to 31 tons per square inch, and 20 per cent. elongation in 8 inches.

Ship angles and beams, 27 to 33 tons per square inch, and 16 per cent. elongation in 8 inches.

A tensile test is taken by the surveyor from every charge or cast from which the plates are made.

Bending test.—A temper bend is taken from every plate, bar, etc., both for ship and boiler material. The test pieces are heated to a low cherry red, and cooled in water of 82° Fahrenheit. They must then stand bending to a curve, the inner radius of which is one and a half times the thickness of the piece.

BOARD OF TRADE.—Only steel which is to be used in the manufacture of marine boilers is tested by the Board of Trade surveyors.

Tensile test.—Furnace plates and plates exposed to flame, 26 to 28 tons per square inch, with 20 per cent. elongation in 10 inches. Shell plates and plates not exposed to flame, 28 to 30 tons per square inch, with 20 per cent. elongation in 10 inches.

A tensile test is required from every plate. 25 per cent. of these tests are made in presence of a Board of Trade surveyor; the others are made by the steel makers. The tensile strength and elongation are stamped on every plate. The letters B T are also stamped on all plates passed by the Board of Trade surveyor.

Bending test.—From every plate exposed to flame, a shearing is taken, heated to a low cherry red, and cooled in water of 82° Fahrenheit. It must then stand bending to a curve, the inner radius of which is equal to one and a half times the thickness of the plate.

In the case of shell plates and plates not exposed to flame, a test piece is taken from each plate and bent cold to a curve, the inner radius of which is equal to one and a half times the thickness of the plate.

The test requirements of other European Governments are usually the same as those of the British Admiralty.

The tendency among English engineers is to use steel still softer than that stated in the preceding test rules. Some large builders will use nothing in their boilers over 26 tons tensile strength per square inch, and 25 per cent. elongation in 8 inches, and advise the adoption of the same test for all structural purposes. Two of the largest consumers in Central England advise the use of steel of from 23 to 25 tons tensile strength per square inch, and 25 per cent. elongation in 8 inches.

Many of the accidents that occurred during the early introduction of steel are ascribed to the use of steel of too high tensile strength, and too low per cent. of elongation; consequently it was brittle and unreliable.

American engineers generally use it from 15 to 20 per cent. higher tensile strength than the English.

"The Steel Company of Scotland" manufactures about 500 tons daily of Siemens-Martin steel, all of which is used for structural purposes. They are now furnishing all the steel for the new "Cunard" all-steel steamer *Umbria*, 8 000 tons register, and all the steel for the New Forth Bridge, about 42 000 tons; yet, in looking over their test book, the highest tensile strength I saw was 34 tons per square inch, which is the maximum allowed on the compression members of the New Forth Bridge, while the maximum tensile strain for tension members is 30 tons.

The Siemens-Martin, or open-hearth steel, is preferred by nearly all consumers for structural purposes. It is used exclusively in many of the largest ship-yards, it being considered more reliable and uniform in its structure and composition than the Bessemer, which is principally used for railroad purposes.

All the shipbuilders with whom I have conversed are very decided in their preference of the Siemens-Martin steel over the Bessemer, or the best Yorkshire iron, including Lowmoor. A member of one of the oldest and largest firms told me that in a given quantity of plates there would be condemned and returned for flaws, or other imperfections, more than fifty times as many plates made of the best Yorkshire iron than those made of Siemens-Martin steel.

Steel is weakened by shearing; the edges of the plates, where subject to heavy strain, are generally planed afterwards; the removal of $\frac{1}{16}$ to $\frac{1}{4}$ inch restores the original strength; annealing also restores it.

Steel is also weakened by punching. Custom and opinion differ as to the best mode of making the holes. Some punch, and afterwards ream out $\frac{1}{16}$ to $\frac{1}{8}$ inch, which removes all the damaged part in thin plates; others drill the holes; others punch the holes, and anneal afterwards, which restores the original strength; while others increase the thickness to compensate for the strength lost by punching.

Mr. Parker, the chief engineer of Lloyd's Register of England, made a large number of experiments on the loss of strength in steel plates by punching, viz.:

For $\frac{1}{4}$ inch	plate,	loss of	strength	.....	8	per cent.
" $\frac{3}{8}$ "	"	"	"	.....	18	"
" $\frac{1}{2}$ "	"	"	"	.....	26	"
" $\frac{3}{4}$ "	"	"	"	.....	28	"

He says that in riveted joints subject to tensile strain the holes should be drilled, or, if punched, should be reamed or annealed after punching, either of which restores the lost strength. Iron of similar thickness showed about equal loss by punching.

There is much diversity of opinion as to the safe working load of mild steel compared to wrought-iron. All admit that, being much more homogeneous and freer from flaws, it can be safely loaded with a working load much nearer to its elastic limit. Some say that the weight, as compared with wrought-iron, can be reduced 40 per cent. (while the most conservative say 25 per cent.), and have a stronger and more reliable structure of steel than if made of iron.

The Board of Trade of Great Britain, which controls the construction of all railway bridges, limits the working strain in tension of wrought-iron to 5 and steel to 6½ tons tensile strain per square inch—an increase of 30 per cent. over iron.

Steel can be manufactured into much heavier, consequently longer and wider, pieces than wrought-iron. I have been offered plates ½ inch thick, 30 feet long, and 7 feet wide. Some manufacturers claim their ability to roll single pieces weighing over four tons.

Steel rivets are used on the Clyde exclusively in riveting steel, giving entire satisfaction, and, wherever practicable, are driven by machinery.

I have never seen any statement published in reference to the expansion of mild steel by heat. Mr. F. W. Dick, superintendent of the "Blochairn Steel Works," Glasgow, has kindly given me the following

results of elaborate experiments made by him to test the practicability of covering wrought and cast-iron guns with steel:

Expansion from 0° centigrade to 100° centigrade.

Mild steel, Siemens-Martin	.00118
Cast-iron	.00111
Wrought-iron	.00121

It may be well to state that the New Forth Bridge, with its 1 700 feet span, is being built of mild steel. It will require 42 000 tons—all manufactured by the Siemens-Martin process.

The oxydation or rusting of steel, in my judgment, has not been satisfactorily tested. Mr. Parker, chief engineer of Lloyd's Register, tried a number of experiments upon iron and steel under the same conditions, the result being in favor of steel.

In 1881 the Lloyd's Register had under inspection 1 100 steel boilers. No difference was found between iron and steel in rusting.

The foreign as well as the domestic market is very much depressed, and the tendency is for still lower prices, especially in the foreign Siemens-Martin steel, owing to the great stagnation in shipbuilding. At the present time Siemens-Martin steel, to stand the preceding tests, could be laid down in New York, freight, duty and insurance paid, at the following prices, viz.:

Plates, ¼ inch and over in thickness	.03 cents per lb.
Girders, beams, etc	.03½ " "

For a large order, a reduction could probably be obtained from these figures. These prices are much lower than our steel manufacturers have been asking for this quality of steel.

The use of mild steel is extending very rapidly in Europe, and is fast superseding iron for structural purposes. Now that its advantages have become known, and the price has been so greatly reduced, even below that of good wrought-iron, its use in the future will rapidly extend.

DISCUSSION.

F. COLLINGWOOD, M. Am. Soc. C. E.—I am quite surprised to hear this statement made, that there is a tendency to reduce the standard rather than to raise it. I am under the impression that the scientific papers have been urging the Board of Trade of Great Britain to increase the standard.

THEODORE COOPER, M. Am. Soc. C. E.—Some four years ago I presented a paper to this Society upon the use of steel for bridges. In it I tried to be very conservative in my recommendations.

If I were to rewrite it now I would be still more conservative. I am not unaware of the great advances that have been made in its application to boilers and the hulls of ships, and that it has given great satisfaction in this direction.

But for structures that come more particularly under the civil engineer's province—bridges, viaducts and similar structures—I would prefer at present the old stand-by, good wrought-iron. For the following reason: the material needed for bridge purposes is not yet a commercial article. We can only obtain a satisfactory article by a most rigid inspection and at a great expense of time and money for testing. The steel plates used for boilers and ships have passed through this stage, and good material can be had. But no one who valued his reputation would accept plates for these purposes except from makers who have developed this branch of steel-making to a satisfactory condition. This must yet be done for bridge steel. Where the circumstances would justify the extra expense, I should, of course, aim to get satisfactory steel.

With a proper inspection, steel tension members can be obtained of a superior quality. I should, however, hesitate to use them without the most cautious inspection; for the defects of steel are not as evident to simply ocular inspection as those of iron.

For compression members, I have yet to find the evidence showing steel to be *as strong* as wrought-iron. I am now speaking of what is called mild steel, and is now furnished for these members. We have but few tests of the compression of steel members, and from these I can only draw the conclusion that steel is weaker than wrought-iron for resisting compressive strains. I have been recently informed by one of our members, who is making some experiments upon steel in compression, that such is also the result of his tests. Therefore, until the

capacity of mild steel to resist compression is proved to be superior to iron, I prefer to use the older material. That time will develop a material suited to bridge purposes, I do not doubt. But I do believe a more rapid advance will be made in the use of this material for structural purposes by going cautiously rather than by rushing blindly into the use of steel for new purposes, without careful tests and inspection.

We may not be able to say positively that steel is weaker than wrought-iron, but to my mind the tests at hand tend to this conclusion. I know there are large structures in which steel has been proportioned for strains in compression from 14 000 to 18 000 pounds per square inch. If such strains must be used, I should, from all the evidence we have at present, prefer to use wrought-iron. In other words, it has not been proven that we can use steel in compression, with safety, to any higher strain than we can wrought-iron.

M. N. FORNEY, M. Am. Soc. C. E.—It may be interesting, perhaps, to members to know something of the extent to which steel is used in the construction of railroad machinery. I will not attempt to refute what Mr. Cooper has said regarding its use for bridges, but in the matter of rails, it may safely be stated that an order for iron rails will soon be a curiosity. Steel is supplanting iron entirely in the use of tires for locomotive and car wheels. There are no wrought-iron tires made at present.

The struggle in this country has been between cast-iron and steel tired wheels. We have in steel a material which has a great capacity for resistance to wear, and in some qualities of cast-iron we have a material which can be chilled so as to produce a surface as hard as the hardest steel, so that the tread of the wheel is adapted to withstand a large amount of wear. Besides this advantage, such wheels can be produced at lower prices than steel tired wheels, and will give a service of from 50 000 to 70 000 miles.

I have had occasion not long since to look up the number of accidents from the breaking of wheels, and it is astonishing to find the large proportion of accidents in this country which may be attributed to that cause. In the record published in the *Railroad Gazette* there were reported during the past five years in this country a little over 5 000 accidents, while the British Board of Trade reported about the same number. In this country 66 per cent. of the accidents are due to derailment, whereas only 8 per cent. are due to the same cause in England.

There are no statistics about the breakage of the wheels here, but more than one thousand broke last winter on one road. The immense number of broken cast-iron wheels naturally has led to a great deal of uneasiness among railroad managers, and the tendency has been to supplant cast-iron wheels with steel tires, because the latter are not so liable to breakage. I will add that the frequent breakage of wheels and the large number of derailments are due to a very considerable extent to the disgraceful condition of the gauge of the wheels and the track in this country. It seems as though each track superintendent lays the track to suit his own fancy. Every engineer who has occasion to have a rail rolled makes a new pattern which he thinks about right. Owing to the fact that so many accidents are due to broken wheels, the use of steel tires is at the present time gaining rapidly over cast-iron.

For axles it is doubtful whether wrought-iron or steel gives best results. In Europe the fire-boxes of locomotives are made of copper. It was so in this country twenty-five years ago, but at the present time a copper fire-box is a great curiosity here. I do not know of one in the whole country. Locomotive boilers are very generally made of steel. So are piston-rods and connecting rods, which are subject to alternate strains of tension and compression. Crank pins, slide bars, links, and many other parts are now all made of steel; so that, though what Mr. Cooper says in regard to the use of steel may be true of bridges, it does not hold good regarding the use of steel for machinery. It is rapidly supplanting cast-iron in many cases, and wrought-iron entirely in others.

THEODORE COOPER, M. Am. Soc. C. E.—With regard to what Mr. Forney says about rails, tires and the parts of the locomotive, it must be borne in mind that each of these requires a special quality of steel. Also that the processes of manufacturing rails and tires have been special branches of manufacture, devoted to developing the proper material and manipulations to obtain the best results.

The sections of a steel rail or a tire are uniform throughout, and all work is done upon them at a uniform and high temperature. The material in them gives excellent results as long as we do not have to punch or break the uniformity of the section.

For the parts of the locomotive a different kind of steel from any of the above is used, and I doubt if the best results can be obtained from any other than crucible steel.

M. N. FORNEY, M. Am. Soc. C. E.—In regard to the locomotive, the plates are exposed to the most violent changes of temperature, from the greatest heat to the injection of cold water into the boiler. A long while ago the use of steel in fire-boxes very nearly came to be abandoned. On the Illinois Central the train men threw a steel plate from a box car on to the platform, and it broke to pieces. In one case on the Lake Shore Road the fire-box went off with a report like a musket. The plates would crack suddenly with a loud report. Another curious fact was that the cracks existed on the side of the fire-box. These facts came very near leading to the abandonment of steel. In this country, when the manufacturers understood the difficulty as to the steel for fire-boxes, they were able to keep it within limits.

It seems to me that in the use of steel for bridges, if a difficulty exist, and it is brought to the attention of the manufacturers, they ought to be able to produce a steel that will contain the qualities necessary for such purposes.

Mr. COOPER.—I think they will in time.

E. B. DORSEY, M. Am. Soc. C. E.—I agree fully with Mr. Cooper, that it is important that engineers should know more of the behavior of steel under compression, and that the experiments made public on this point are very few, and, generally, on too small a scale to be reliable; for this reason I regret very much that Mr. Cooper did not give us the experiments upon which he bases his conclusions.

My investigations were confined entirely to finding the best metal—wrought-iron or mild steel—for resisting tensile strain, and not for compression.

Mr. B. Baker, of Baker & Fowler, the engineers of the New Forth Bridge, in a paper published in the *Engineering* for September 8th, 1882, page 230, says:

"The author's experiments conclusively prove that steel is far superior to iron as a material for struts, though the superiority is not so great as when tension members are in question. Thus the Forth Bridge struts will be from 30 to 40 per cent. stronger in steel than in iron, whilst the tension members will be about 50 per cent. stronger. It does not follow that the steel strut would not be 50 per cent. better also as regards actual work, which is very different to what takes place in a testing machine. A steel or an iron rail, tested for transverse strength in a machine, will, as a rule, bend many inches, and fail by distortion of

the head under the compressive stress. In actual work hundreds of such rails break, but it is the tensile and not the compressive stress which causes the failure, and there is no distortion of the head as in the testing machine. Similarly, when riveted girders break under traffic, it is not the top flanges with a calculated stress on the average of about one-third of the ultimate resistance that give way, but the bottom members, where the calculated stress is only about one-fourth of the ultimate resistance. In short, the universal experience is that fatigue is far more injurious to iron or steel under tensile than under compressive stress, and it follows that the factor of safety should not be the same in the two cases. This is quite consistent with ordinary practice, for probably the majority of girder bridges in this country have equal-sized top and bottom flanges, which, after allowing for the riveting, would give a factor of about 3 for the compression and about 4 for the tension members, respectively.

"The peculiarities of steel are tolerably well understood now, and, amongst other precautions, it is especially desirable to so design the joints in tension that no tearing action shall be set up along a line of rivet holes. Accidents of workmanship necessitate the provision of a good factor of safety in steel joints in tension; but, after watching the testing of many steel tubes under compression, the author cannot conceive any accident of workmanship which could bring about the failure of steel tubes such as those in the Forth Bridge, even if the working stress was raised to two-thirds instead of about one-fourth of the ultimate resistance. In fine, he believes a steel tube to be the most trustworthy member which could be introduced into a great and unprecedented work."

Unfortunately, he does not mention or describe in detail his experiments, so that we can form our own conclusions, but we must judge that before he and his associates decided to build this unprecedented cantilever bridge all of steel, with two spans of 1 700 feet each, the experiments must have been very thorough and on a very large scale.

This is a very important subject, and I think the Society would do well to invite more discussion upon it.

It is probable the use of steel in the near future in structural works will be very large, especially in railroad bridges; it is very important to all that its qualities under compression in large working pieces should be better understood.

This Society should urge upon our Government to make a liberal appropriation to have these tests made at the Watertown Arsenal, as the testing machine there is the only one available in the United States of sufficient capacity to make these tests on large pieces such as are used in bridges or other large structural works. The few tests that have been made show that large pieces are much weaker in proportion than small ones.

Every traveler who crosses a bridge in a railroad car is interested in these tests.

Our Government is spending millions of dollars in building men of war of steel, without knowing how it will act under compression—its action under tension is well understood. It is probable that hundreds of thousands of dollars could have been saved if these proposed tests had been made before the contracts were let, and that the ships would have been better.